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CAPABILITIES OF SEDIMENT IN THE
SOUTHWEST

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Introduction

Watershed studies commonly attempt to quantify nutrient loss as a means of evaluating the effects of land management operations. This procedure is used to address changes in site productivity as well as stream and lake eutrophication. Normally, such studies measure dissolved ion concentrations and ignore a potentially important loss of available ions transported by the suspended sediment load. Many studies have been made of sediment loss in the west, but virtually none have addressed the nutrient and heavy metal transport capacity of this material.

The combination of a given geology and a given vegetation type (the vegetation type reflecting the other parameters of the physical environment, such as moisture and temperature) should produce a characteristic weathering regime which will greatly influence the physical and chemical characteristics of the sediments produced. While a given site may lose a greater quantity of sediment than another of similar vegetation and geology, the characteristics (nutrient and heavy metal transporting capacity) of similar sediment size fractions should be similar. In order to test this hypothesis we chose to compare samples from ponderosa pine communities on basalt, sandstone, limestone, and granite; and to compare a ponderosa pine community and a mixed conifer community on basalt.

The specific objectives of this study were: 1) to develop or identify the best analytical methodology for characterizing the adsorbing capacity of different types of sediments (e.g. clay, silt, sand) as related to

the transport of the potentially available nutrients from different sediment sources. 2) to identify the differences in the chemistry and transport capacity of sediments with respect to source (geology and vegetation type) and to the length of time sediments have been in the stream channel.

General Site Description

Beaver Creek Watershed (ponderosa pine on basalt). Samples were collected on Beaver Creek Watershed #13 in late May, 1978. The watersheds had experienced very heavy rainfall in October, 1977, which had a scouring effect on the stream channels. As a result, there were no definable log steps or rock steps and the sediment collected was trapped between the rocks in the stream channel. The bank material was collected from areas left undisturbed by the storm. Gambel Oak (Quercus gambelii Nutt.) comprises a considerable portion of the vegetation on Beaver Creek Watershed #13. As a result, soil samples were also taken under Gambel Oak. Mineral identification of the greater than 2mm size fraction characterized this material as amygdaloidal andesite. The andesite material had the following relative % composition: Ca-plagioclase 60%, Na-plagioclase 20%, magnetite 15%, quartz 5%, and trace minerals including K-feldspar, olivine, and biotite. The rocks were moderately to highly weathered.

Heber Watershed (ponderosa pine on sandstone). The samples were collected in late May, 1978, and the area did not appear to be severely eroded. Samples were taken above the clearly definable log steps and rock steps. Samples were also taken of the bank and 0-15cm soil depth below ponderosa pine. Mineral identification characterized the greater than 2mm size fraction as orthoquartzite with varying amounts of magnetite, micas, and other components of a granitic gneiss.

Sacramento Forest (ponderosa pine on limestone). The originally proposed site for the ponderosa pine community on limestone was the Long Valley Research Forest in Arizona. Inspection of the area in 1978 found substantial disturbance by recent road construction and logging activities. The limestone was not continuous throughout the whole area and underlying sandstone and other geologic formations had been exposed by the activities. As a result, a ponderosa pine forest on limestone was selected in the Sacramento Forest east of Cloudcroft, New Mexico. The vegetation in the upper one-third of the watershed was comprised of a mixture of ponderosa pine and mixed conifer species. The lower two-thirds was comprised of ponderosa pine with grasslands in the valley. The stream channel was not definable throughout the entire length of the watershed. The grassland meadow in the valley did not have a distinguishable stream channel. This appears to be a common feature of ponderosa pine communities on limestone as the Long Valley Watersheds also had a considerable portion of the valley comprised of grasslands with no definable stream channels. Samples were taken of the 0-15cm soil depth under ponderosa pine, bank material, and stream channel material. However, because of the lack of a definite stream channel in many portions of the watershed the samples labeled channel sediment perhaps should be loosely interpreted. Mineral identification of the greater than 2mm size fraction characterized the material as a marine limestone composed primarily of CaCO_3 , with smaller amounts of MgCO_3 , with 5-10 percent chert. Most of the rocks were highly weathered and the fine material in the pores were high in organic material.

Tesuque Watersheds (ponderosa pine on granite). The watershed had a definite stream channel and the beginnings of log steps and rock steps,

however, the steps were not developed to the point where we felt separation should be made between these two types of samples. Samples were also taken of the bank and 0-15cm depth under ponderosa pine. It should be noted that the valley bottom of the watershed supported a mixed conifer community, however, the vast majority of the slopes of the watershed were ponderosa pine with a small amount of Gambel Oak. Mineral identification of the greater than 2mm size fraction characterized this material as pre-Cambrian granitic gneiss composed of the following materials (ranging from most to least abundant): K-feldspar, quartz, biotite, and other micas, plagioclase, epidote, almandite, sillimanite, and other trace minerals. Weathering was only slight to moderate (as shown by the angular grains).

Thomas Creek (mixed conifer on basalt). Thomas Creek Watershed had the best developed log steps and rock steps of any of the watersheds sampled. Thus, samples were taken of log step, rock step, bank material, and 0-15cm depth below the mixed conifer canopy. Mineral identification of the greater than 2mm size fraction characterized this material as amygdaloidal basalt. The relative composition of the minerals is as follows (ranging from the most to least abundant): Ca-plagioclase, magnetite, hornblende, Na-plagioclase, quartz, and other trace minerals. Weathering was intense and the rocks were highly altered with substantial amounts of indistinguishable matrix material.

Sample Collection and Handling Methodologies

We felt if the analyses were to be representative of the forest communities present in a very broad geographic area, distinct differences should be detectable with a small sample size. Thus, we chose a sample size of three replicates per type of material per area. All samples were

collected in clean, sterile, 18 oz. plastic bags. Triplicate samples were taken of the 0-15cm depth soil below the forest canopy, bank material, and stream sediment (which was further separated into log steps and rock steps if these geomorphological features were present in the stream channel). The samples were bulk samples composed of all the various size particles (including inclusion rocks) and organic and inorganic material present at the sampling location. The sample was not necessarily representative of the proportion of size fractions which would be found throughout the entire watershed, but did contain all size fractions which would be present in the area. It is important to stress that these proportions may not be representative of the size fractions lost from the watershed as transported sediments at any given time.

All samples were transported to a laboratory in Albuquerque. Samples which were too moist for sieving, were allowed to dry to the point at which they could be properly sieved. It is important to stress that the samples were never allowed to become completely air dried since this can shrink the clay plates and trap ions in the process and yield low results for exchangeable cations and cation exchange capacity (R.Reynolds, Dartmouth College, personal communication). After the samples were allowed to dry to the proper condition, the samples were sieved through a 2.0mm sieve. The less than 2.0mm size fraction was then separated into two fractions; one fraction which was sieved through a 0.061mm sieve and the other proportion remained intact. The material which passed through the 0.061mm sieve was termed the fines and the greater than 0.061mm size fraction was termed sand. The material in the sand fraction was then washed with deionized water to remove smaller particles which were not removed by sieving. Finally, all fractions were split into two portions;

one remained fresh and the other was oven dried. This process resulted in two separate portions (fresh and oven-dried) which were in three distinct fractions (total, sand, fine). The oven-dried samples were analyzed for heavy metals, major cations and total N and P. The proportions that remained in the fresh condition were analyzed for extractable Ca, Mg, K, cation exchange capacity, organics and all textural analyses (with correction factors applied to this material to correct to dry weight). The samples that were left in the greater than 2.0mm sieve were analyzed for the relative proportion of the minerals present. All x-ray diffraction analyses were performed on fresh material.

Analytical Method Development

Most of the methods in this report were adopted from standard methods employed for analyses of environmental samples. Black (1965) was the primary reference.

We set three criteria to evaluate the methods. The first was that the method had to yield reproducible results within sample replicates. All methods have yielded replication within 5 percent, and often the results are reproducible to three significant figures.

The second criterion was the method had to yield reproducible results on all the various size fractions. We anticipated that the separation of the samples into the size fractions might partition the material in such a manner that one fraction would contain a different matrix and potentially interfere with the analysis. To test this, all samples were checked for interferences and routine analyses included concurrent analysis of standards and blanks. The method of standard additions was performed on the final solution to determine the existence of matrix interferences. The

final technique employed to evaluate the method was to sum the amount of the measured constituent in the separate sand and fine fractions multiplied by the respective percent composition (determined by the textural analysis). The sum of the two fractions should equal the value obtained on the original total sample (within 5 percent).

The third criterion was the method should be suitable for routine analysis. Consideration was given to the method which would meet the first two criteria and would be the least costly in terms of personnel and supplies.

Analytical Methodology

Cation exchange capacity and exchangeable cations:

Place 5.0 grams of fresh material into a screw cap centrifuge tube. Eight extractions with 27ml of 1.0 N ammonium acetate (buffered at pH 7.0) are to be performed as follows:

1. Add 27ml of extraction solution to the tube.
2. Shake soil and solution for 5 minutes (inspect sample to make sure all aggregates are dispersed).
3. Let solution and soil lay for 5 minutes to achieve a more complete extraction.
4. Centrifuge at about 2000 rpm for 5 minutes or until clarified.
5. Decant off solution into a funnel fitted with a rinsed Whatman #42 filter paper, filtering directly into a 250ml volumetric flask.
6. Perform the above steps a total of 8 times and after the final extraction, rinse down filter paper 3 times with extraction solution.

7. Bring solution to 250ml volume with extraction solution.

The solution obtained at this stage is analyzed for cations to obtain a total extractable cation concentration. Transfer all material in the funnel back to the centrifuge tube and replace filter paper. Extract the soil four times with 40ml of neutral pH 1.0 $\underline{\text{N}}$ NH_4Cl and once with 40ml of 0.25 $\underline{\text{N}}$ NH_4Cl . Rinse 5 times with 40ml of isopropyl alcohol to remove all electrolytes. Transfer all material in filter paper to centrifuge tubes and replace filter. Extract the soil with 8 separate 27ml portions of 10% NaCl (acidified with HCl to obtain a 0.005 $\underline{\text{N}}$ HCl concentration) using the same steps for the ammonium acetate extractions. The resulting solution collected in the 250ml flask is then analyzed for ammonium on a Technicon AutoAnalyzer to determine the cation exchange capacity.

This procedure was designed because the extraction with 250ml of 1.0 $\underline{\text{N}}$ ammonium acetate (Black 1965) did not yield reproducible results nor did 3 extractions with 33ml of sodium acetate (Black 1965). The ammonium solution did not interfere with the analyses on the atomic absorption techniques and the cation exchange capacity measurements with the ammonium replacement met all the set criteria for the method. The extraction procedure was performed and each extract was saved and analyzed separately for cations to determine the point at which measurable quantities of cations could not be extracted. Figure 1 is a plot of the percentage of the exchangeable cations removed after each extraction in relation to the total extracted for sediment from Beaver Creek WS-#13. Other material displayed similar extraction plots. After about 6 extracts, all but one or two percent of the total cation was extracted. It should be noted that this technique may dissolve some soluble salts and all the cations removed are not necessarily on exchange sites. A preferred technique would be to

extract all materials with an extraction solution buffered at the pH of the representative material. However, it would be very time consuming to prepare an individual extraction solution buffered at the pH of each material. We feel the technique we used is an adequate compromise which yields reproducible results with the least time and expense.

Total Nitrogen and Phosphorus:

A modified Kjeldahl digestion was performed for the analyses of total nitrogen and phosphorus. A 1.0 gram oven-dried sample was placed in Technicon BD 20 digestion tube. Ten ml of concentrated sulfuric acid and 5 grams of copper sulfate-potassium sulfate mixture was added to each tube. Copper sulfate was used in place of mercuric oxide as a catalyst because the color added to the sample by copper sulfate is very beneficial in indicating end points during the procedure. The tubes were warmed on the digestion block, removed, and 1 ml of 30% hydrogen peroxide was added stepwise (up to a maximum of 10ml with heating between additions) to the digestion flasks to oxidize the organic matter. The samples were digested at 350°C (this temperature is lower than recommended in the Technicon method because the solution will not condense at higher temperatures due to the lower atmospheric pressure at the elevation of Albuquerque). The solution initially turned black after heating, then turned blue-green when the digestion was complete. The samples were removed from the block, cooled, and brought up to volume of 250 ml. The samples were stirred with a magnetic stirrer placed in the tube and allowed to settle for 24 hours (this allows most of the fine silica material to settle which otherwise causes scattering of the light during the analysis and increased values). Part of the settled sample was drawn off and diluted by 5 fold and then run on the Technicon AutoAnalyzer for N as ammonium and P as ortho-phosphate. Standards and blanks were processed through the entire digestion

procedure and were used to calibrate the appropriate analytical test cartridge. The standards did not differ between individual sample runs, and later sets of samples excluded digestion of standards and the standards were made up from the blank solution digested with each set.

Digestion for major cations and metals:

The acid digestion of Anderson (1974) was used to determine potentially available metals and cations (including exchangeable, precipitated, chelated, and easily digestible). The HNO_3 and HCl digestion technique is widely used for this purpose (M.R. Sommerfeld cited this technique to be used in the study "Sediment transport of heavy metals and nutrients in a reclaimed forest watershed." E.C. Study #259). A 1.0 gram sample was digested with 10ml HNO_3 and 10ml HCl with subsequent additions of equal volume of both acids until the digestion was complete. The sample was filtered through a Whatman #42 filter into 100ml volumetric flask with repeated rinsing of the paper and brought to volume with water. This solution was then analyzed for Ca, Mg, Na, K, Zn, Fe, Cu, Mn, Pb, and Cd. Digested reagent blanks were run with each set of 19 samples.

The digested solution was then analyzed on a Perkin Elmer model 306 Atomic Absorption Spectrophotometer using the appropriate flame or heated graphite furnace technique. Ca and Mg were analyzed with lanthanum additions to prevent ionization in the flame. Na, K, Zn, Cu, Mn and Fe were all run directly on the flame with appropriate standards made up in acid solutions. Pb and Cd required heated graphite furnace analyses and were performed using the method of additions.

The Beaver Creek Watershed samples were run as individual samples for Cd. These data clearly showed the variation to be too large for 3 replicates to yield significant mean values, thus, we decided to composite the triplicate samples into one sample and run the composited sample for Cd on all other sites.

Organic Matter Analyses:

The originally proposed method for analyses of organic matter on the sediments (Maciolek, 1962) was found to be unsatisfactory for many reasons. The method was too costly in terms of time and reagents to be performed on a routine basis, the high particulate mineral content of almost all samples masked the end point of the titration making accurate titration very difficult, and the geologies varied in potential interfering constituents. Comparative analyses were performed with a loss upon ignition at 500°C method, and the results were not significantly different between the different methods. Loss upon ignition method has been utilized by other researchers to determine either organic matter content or carbon content of organics soils (St. John and Rundel, 1976). Considering the number of analyses and the degree of accuracy needed, we feel that the loss upon ignition method was adequate for this study.

Textural Analyses:

The Bouyoucos' hydrometer method was used for textural analyses (Black 1965), however, we feel the following notes are important: 1) Organic matter in the sample shows up as sand in this analysis (the weight of the organic matter is included in the initial weight, however, it does not add to the buoyancy of the hydrometer bulb). 2) A significant blank reading for the Na-hexametaphosphate and peroxide was found, and it was necessary to subtract the blank readings from all readings to obtain

accurate analyses. 3) Analyses on 100, 50 and 25 gram samples yield the same results when blank corrections were applied.

Mineral Identification:

The greater than 2mm size fraction of the three replicates were bulked into one sample and visual identification of the material was performed. Some samples required washing to enable visual identification.

X-ray Diffraction Analyses:

The primary reference for the technique is Carroll (1970). Analyses were performed on material treated in various manners to determine the best type of material to be used for the analysis. The first analysis was performed on fresh material in the less than 2.0mm size fraction (totals). The x-ray diffraction analysis was satisfactory, however, the sensitivity on the clay peaks was quite low, and in hopes of increasing the sensitivity, various procedures were used. The fine fraction was analysed, and the analysis was not significantly different than the original total sample. Then, the material left in suspension at the end of the hydrometer analysis was siphoned off and treated with a concentrated solution of MgSO_4 which flocculated the suspended clays. This flocculated material was centrifuged, then processed for x-ray diffraction analyses. None of the flocculated material had satisfactory x-ray analysis spectrographs. Perhaps this material was amorphous and had no platy-structure or the MgSO_4 did not allow for adequate dispersion of the clay particles in the plating technique and thus aggregates were actually plated on the glass slide which did not allow for the proper orientation of the clay particles. Since the original untreated materials provided as sensitive detection for the clay particles as any of the other techniques, all samples were analyzed on the original untreated less than 2.0mm size fraction. X-ray

diffraction analysis does not yield quantitative data, only the presence of a certain type of clay can be determined.

Results

In general, one 18 oz. bag of material was enough to perform all the analyses. There were only a few instances when there was insufficient material of all size fractions to perform the analyses.

The data in Tables 1 through 18 allows for the testing of many of the original hypotheses. Most of the analyses on the different size fractions yielded standard errors less than 10% of the mean (or close to 10%). The only analyses which consistently yielded standard errors greater than 10% of the mean were Pb and Cd (as mentioned earlier for Cd). Thus, the original sample size of three replicates per material per site was adequate to yield satisfactory values for all analyses except Pd and Cd.

The second hypothesis was that the bedrock was a major factor in determining the amount of nutrients and heavy metals to be transported by the sediments. Tables 19 and 20 show comparisons of soil, bank and sediment from all the geologies with ponderosa pine vegetation. The importance of geology can be seen between sites. The limestone site has the highest calcium values as would be expected and the basalt has the highest metal content typical of volcanic regions.

The final hypothesis to be tested is the effect of vegetation on nutrient content of transported material. Table 21 contrasts ponderosa pine and mixed conifer communities on the same bedrock (basalt). Some of the differences shown in the table can be explained by the differences in the original bedrock material. Beaver Creek Watershed had a higher Na-plagioclase concentration than did the Thomas Creek Watershed and as a result the Na concentrations were significantly higher in the Beaver Creek (pine) than

in Thomas Creek (mixed conifer). Accordingly, the differences seen in other metals can be attributed to the differences in bedrock. However, the increase in K, P, cation exchange capacity, and organic matter could be attributed to biological communities present and/or the physical environment differences.

Close inspection of the data reveals a few trends related to the processing of the soils. During the sieving process, the sample was sieved through the 0.061mm sieve until there was no more visible increase in the material in the bottom pan. Subsequently, the material remaining in the sieve was washed to remove all material less than 0.061mm which would have been attached to the larger size material, with this material being completely lost from the sample. This process apparently had some effects upon the results. If the concentration of a parameter in a given size fraction is multiplied by the relative proportion of that size fraction, the sum of the two fractions should equal the value for the total sample (a test used to verify the technique mentioned earlier). Summing the relative proportion of the two different size classifications for Total P and cation exchange capacity often yielded a value less than the total sample value. We hypothesize that the sieving process increased the relative abundance of silt to clay in the fine fraction and most of the material which was attached to the sand size fraction were clay particles which would have the highest C.E.C. and possibly the highest P content. Thus, rinsing of the sand fraction removed this material and the value obtained for the fine fraction is too low in the relative proportion of P and cation exchange capacity. Further investigations will be done to verify whether or not this is the case.

One matter of importance is whether in-situ sediment collected from the streams is truly representative of sediment which would be transported during stream flow. Table 22 compares transported sediment composited from samples taken from the settling tanks on the Beaver Creek Watersheds to sediments collected on site at Beaver Creek WS #13. For the major nutrients (Ca, Mg, etc.) the values were remarkably close with the largest discrepancy occurring for Zn and other metals. We attribute this to contamination by the galvanized steel basins in which the transported sediment was trapped. These results very strongly support the hypothesis that sediment can be sampled before being transported to obtain representative values.

The two locations which gave the best x-ray diffraction analyses were Heber and Tesuque. The four different sample types at Heber (0-15cm, bank, rock step, and log step) all had a strong illite peak, and a medium to strong chlorite peak. All Tesuque samples (stream sediment, bank, 0-15cm soil) had strong illite and kaolinite peaks with weak vermiculite peaks, however, further analyses are needed to verify presence or absence of vermiculite. The Sacramento Mt. samples all had strong illite and kaolinite peaks with possibly montmorillonite. All samples from Beaver Creek and Thomas Creek gave poor x-ray diffraction analyses with illite the only clay to definitely show up in any of the samples (montmorillonite, chlorite and kaolinite are weakly suggested). We feel confident there are other clays present and are currently pursuing the reason for the poor x-ray diffraction analyses on these samples. A possible cause could be higher organic content of these soils, because the Sacramento Mtns. (which also had high organic content) did not yield very good quality x-ray diffraction analyses. Perhaps the organic matter interacts with the clay particles and does

not allow for proper plating on the glass slides and hence for proper orientation of the particles for x-ray diffraction analyses.

Of the clays detected by the x-ray diffraction analyses, kaolinite (3-15 meq/100g) had the lowest cation exchange capacity of those clays measured; illite and chlorite have a cation exchange capacity of approximately 20-80 meq/100g; montmorillonite has approximately 80-100 meq/100g; and vermiculite has greater than 100 meq/100g cation exchange capacity.

The cation exchange capacity of the suspended clays which were si-phoned off at the end of the textural analyses is shown in Table 23. The samples taken at the Tesuque Watershed show the highest cation exchange capacity for the suspended clay material, and these were the only samples which suggested that vermiculite clays would be present. The cation exchange of the Heber samples is in the general range for samples having illite, kaolinite, or chlorite clays (considering the contribution of organic matter). The samples from the Sacramento Mtns. have a cation exchange capacity on the upper end of illite and the hint of montmorillonite in the x-ray diffraction analyses is probably supported by the cation exchange capacity being in the range of montmorillonite. The cation exchange capacity of the samples from Beaver Creek and Thomas Creek are very similar to the range found in the other three areas. Although the x-ray diffraction analyses were not of high quality, the suggestion of the presence of illite, montmorillonite, chlorite and kaolinite in these samples would be strongly supported by the range found in cation exchange capacities for the samples from both Beaver Creek and Thomas Creek.

It should be noted at this time that the measurements of cation exchange capacity on the suspended clay material have a certain degree of doubt. It was difficult to perform the various extractions without the

loss of some of the clay from the centrifuge tubes. Most of the clays lost were of an oily nature and did not lend themselves well to transfer from the filter paper back into the centrifuge tubes. Therefore, some of the original material was lost. The procedure was modified to collect the remainder of the soil in the centrifuge tube at the end of extraction and over-dry this material to obtain an oven dry weight of the clay.

Discussion and Interpretation

One means of graphically presenting the results is shown by Figures 2 through 6. The trilinear graph serves as a means of plotting cations (expressed in meq) for the samples indicated. Plotting the relative proportions in such a manner negates the absolute quantities and presents them in proportion to the total. Thus, samples which have vastly different absolute quantities but similar relative proportions would plot on the same area of the graph.

A few general trends can be detected from the graphs. The relative composition of the extractable cations is closely related to the composition of the cations adsorbed on exchange sites of soil particles and organic matter. In contrast, the relative composition of cations in the acid digestable fraction would reflect the chemical composition of the primary minerals. At all sites, the relative proportion of calcium in the extractable cations increases in relation to the percentage of calcium in the acid digestable fractions. The increase in calcium can be attributed to the higher replacement capabilities of calcium on the exchange sites of soil particles in relation to the other cations (as a result of the weathering process).

Another trend can be seen when contrasting the plots for the samples high in mineral content (0-15cm soil and rock steps when present) to the more highly weathered and/or organic content samples (sediment, bank, or log steps when present). The soils higher in mineral content plot closer to the magnesium apex than do the other samples which plot closer to the calcium apex. This again, can be attributed to the higher degree of weathering of the mineral material for those samples which plot closer to the calcium apex resulting from the higher exchange capacity for calcium than other cations.

The only detectable difference shown by the trilinear graphs between vegetation types (contrasting Beaver Creek to Thomas Creek) is possibly the closer grouping of the different types of samples in the Thomas Creek Watershed than in the Beaver Creek Watershed. Also the samples tend to be closer to the calcium apex (100% Ca) in Thomas Creek than in Beaver Creek. Both of these factors would represent more highly weathered bedrock material at Thomas Creek than at Beaver Creek. This conclusion is also substantiated by the visual identification of the minerals from both locations which showed the Thomas Creek samples to be less angular and more highly weathered than the Beaver Creek samples.

The trilinear plots suggest that the weathering of different bedrock types yields material of more similar chemical composition. The climatic conditions should be similar between site with the same vegetation, and thus, it appears that climate (or vegetation) exerts the same influence upon the chemical weathering products of different materials.

Figure 7 is a graph by which nutrient loss via transported sediment can be determined knowing bedrock type and sediment load. The nutrient content of the sediments from each location determines the slope of the

line for that location. For example, given the annual sediment load data for any given water year at Beaver Creek WS-13, one could determine the amount of exchangeable Ca transported by the fine fraction of the sediment using the appropriate bedrock slope.

Summary

There are some distinct differences in nutrient and heavy metal content from sediments derived from ponderosa pine forest with different bedrock. In general, the relative content of nutrient and heavy metals were as follows (ranging from highest to lowest): basalt, limestone, granite, sandstone. The sediments derived from the mixed conifer community were considerably higher in some of the nutrients (N, P, K) than the ponderosa pine community on the same bedrock. This higher content may be a result of higher nutrient content litter produced in the mixed conifer community (this factor is currently being investigated in the current Eisenhower Consortium Grant). There does not appear to be much difference in the heavy metal content of the sediments derived from the two different vegetation types on the same bedrock. This factor is probably due to the very similar and high metal content of the basalt materials at both locations. Comparing different vegetation types on another bedrock may result in significant differences in metals particularly when the bedrock is very low in metal content and any differences would be the result of the factors associated with the vegetation.

With the exception of primarily Pb and Cd, a sample size of 3 was adequate to yield standard errors less than 10% of the mean (given the methods of handling and analyses performed on the samples). This information accompanied by the trilinear plots of the major cations at all locations supports the assumption that within the same vegetation type (and associated

climatic regimes), similar factors are affecting the various bedrock types in similar manners, and are yielding sediments of similar relative chemical composition. With different vegetation types (and different climatic regimes), the factors may change and may yield sediment of different relative chemical composition than the ponderosa pine communities sampled in this study.

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Table 1. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under ponderosa pine at Beaver Creek WS-13. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.613 / 0.012	0.313 / 0.037	0.569 / 0.021
Mg %	1.47 / 0.044	6.48 / 0.45	0.67 / 0.023
Na ppm	239 / 9.9	128 / 4.6	201 / 8.4
K %	0.26 / 0.015	0.039 / 0.002	0.237 / 0.006
Zn ppm	79.4 / 0.6	126 / 2.85	66.3 / 1.20
Fe %	5.47 / 0.43	11.4 / 0.12	4.9 / 0.13
Cu ppm	72.0 / 2.6	52.3 / 1.8	71.3 / 2.9
Mn %	0.119 / 0.001	0.148 / 0.003	0.104 / 0.006
Pb ppm	28.6 / 17.9	1.67 / 1.2	9.0 / 1.0
Cd ppm	0.30 / 0.069	0.36 / 0.078	0.26 / 0.13
<u>Total</u>			
N %	0.237 / 0.029	0.086 / 0.025	0.192 / 0.035
P %	0.085 / 0.003	0.076 / 0.002	0.049 / 0.004
<u>Extractable</u>			
Ca %	0.460 / 0.017	0.358 / 0.046	0.489 / 0.038
Mg %	0.11 / 0.001	0.082 / 0.009	0.098 / 0.006
K %	0.036 / 0.0025	0.020 / 0.001	0.035 / 0.003
C.E.C. meq/100g	45.6 / 0.52	27.4 / 4.5	35.3 / 3.4
Organic Matter %	11.2 / 1.34	9.08 / 1.59	12.6 / 0.3
<u>Texture</u>			
Sand %	30.9 / 1.4		
Silt %	36.6 / 1.1		
Clay %	32.5 / 0.7		

Table 2. Nutrient and heavy metal content of the total, sand, and fine fractions of the bank material at Beaver Creek WS-13. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.843 / 0.073	0.379 / 0.023	0.871 / 0.092
Mg %	1.21 / 0.09	3.96 / 0.14	0.536 / 0.011
Na ppm	292 / 13.0	249 / 4.9	227 / 17.6
K %	0.32 / 0.026	0.088 / 0.013	0.32 / 0.031
Zn ppm	104 / 1.2	117 / 0.9	97 / 2.6
Fe %	5.24 / 0.16	10.1 / 0.7	3.61 / 0.12
Cu ppm	51.3 / 1.9	44.7 / 2.9	45.7 / 1.8
Mn %	0.195 / 0.010	0.229 / 0.014	0.126 / 0.006
Pb ppm	13 / 1.5	8.7 / 0.9	10.3 / 0.9
Cd ppm	0.49 / 0.012	0.48 / 0.051	0.36 / 0.055
<u>Total</u>			
N %	0.377 / 0.013	0.064 / 0.008	0.408 / 0.026
P %	0.157 / 0.023	0.126 / 0.008	0.098 / 0.005
<u>Extractable</u>			
Ca %	0.601 / 0.058	0.438 / 0.049	0.710 / 0.070
Mg %	0.089 / 0.006	0.064 / 0.008	0.091 / 0.007
K %	0.070 / 0.029	0.052 / 0.015	0.090 / 0.026
C.E.C. meq/100g	51.5 / 1.8	38.7 / 1.4	42.5 / 2.8
Organic Matter %	12.1 / 0.3	6.2 / 0.12	15.0 / 0.74
<u>Texture</u>			
Sand %	39.3 / 3.7		
Silt %	35.1 / 2.0		
Clay %	25.6 / 1.7		

Table 3. Nutrient and heavy metal content of the total, sand, and fine fractions of the stream and sediment at Beaver Creek WS-13. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.457 / 0.023	0.417 / 0.031	0.572 / 0.040
Mg %	1.12 / 0.23	3.62 / 0.32	0.82 / 0.035
Na ppm	177 / 9.6	580 / 4.7	448 / 101
K %	0.118 / 0.012	0.052 / 0.004	0.189 / 0.012
Zn ppm	56.5 / 2.5	88.0 / 1.1	70.7 / 5.8
Fe %	4.91 / 0.23	8.76 / 0.65	5.11 / 0.28
Cu ppm	59.7 / 3.9	53.0 / 1.5	91.7 / 7.5
Mn %	0.220 / 0.060	0.357 / 0.070	0.189 / 0.050
Pb ppm	12.7 / 1.8	7.3 / 0.9	14.7 / 2.3
Cd ppm	0.283 / 0.072	0.593 / 0.088	0.317 / 0.055
<u>Total</u>			
N %	0.103 / 0.007	0.026 / 0.005	0.090 / 0.010
P %	0.110 / 0.010	0.098 / 0.010	0.065 / 0.010
<u>Extractable</u>			
Ca %	0.283 / 0.047	0.138 / 0.018	0.243 / 0.010
Mg %	0.090 / 0.017	0.044 / 0.006	0.098 / 0.016
K %	0.019 / 0.0018	0.011 / 0.0007	0.023 / 0.0021
C.E.C. meq/100g	34.1 / 6.1	13.5 / 1.8	44.8 / 12.1
Organic Matter %	6.13 / 0.82	4.52 / 0.66	8.67 / 0.55
<u>Texture</u>			
Sand %	53.2 / 9.1		
Silt %	21.1 / 2.8		
Clay %	25.7 / 6.5		

Table 4. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under oak at Beaver Creek WS-13. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.733 / 0.034	0.422 / 0.031	0.797 / 0.018
Mg %	0.640 / 0.026	4.36 / 0.26	0.543 / 0.012
Na ppm	126 / 5.5	392 / 13.6	247 / 14.5
K %	0.245 / 0.005	0.047 / 0.001	0.305 / 0.007
Zn ppm	68.4 / 2.0	92.7 / 7.9	73.2 / 3.5
Fe %	2.27 / 0.043	8.41 / 0.21	3.22 / 0.082
Cu ppm	65.9 / 3.3	39.0 / 2.6	76.7 / 3.2
Mn %	0.082 / 0.001	0.099 / 0.014	0.093 / 0.003
Pb ppm	27.3 / 13.5	4.6 / 3.7	28 / 14.6
Cd ppm	0.33 / 0.042	0.29 / 0.040	0.29 / 0.081
<u>Total</u>			
N %	0.407 / 0.032	0.115 / 0.031	0.322 / 0.022
P %	0.098 / 0.006	0.100 / 0.005	0.064 / 0.001
<u>Extractable</u>			
Ca %	0.540 / 0.030	0.353 / 0.043	0.637 / 0.011
Mg %	0.102 / 0.004	0.069 / 0.004	0.104 / 0.005
K %	0.057 / 0.010	0.024 / 0.0019	0.053 / 0.003
C.E.C. meq/100g	50.2 / 2.3	28.5 / 5.2	40.6 / 2.8
Organic Matter %	9.36 / 2.06	— —	13.6 / 0.4
<u>Texture</u>			
Sand %	31.5 / 2.64		
Silt %	35.9 / 2.21		
Clay %	32.5 / 0.47		

Table 5. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under ponderosa pine at Heber WS. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl Digestable</u>			
Ca %	0.066 / 0.004	0.040 / 0.007	0.143 / 0.025
Mg %	0.063 / 0.004	0.021 / 0.002	0.139 / 0.009
Na ppm	32 / 12.2	6.67 / 1.45	58.7 / 5.49
K %	0.058 / 0.004	0.025 / 0.002	0.119 / 0.016
Zn ppm	15.1 / 1.51	6.0 / 1.15	30.7 / 2.73
Fe %	0.523 / 0.056	0.226 / 0.024	1.14 / 0.108
Cu ppm	6.3 / 1.7	2.0 / 0.1	20.7 / 2.03
Mn %	0.017 / 0.002	0.009 / 0.002	0.034 / 0.004
Pb ppm	10.3 / 6.3	3.7 / 1.4	20.3 / 10.9
Cd ppm	0.02 / —	<0.01 / —	0.11 / —
<u>Total</u>			
N %	0.040 / 0.006	0.039 / 0.006	0.051 / 0.008
P %	0.015 / 0.001	0.0037/ 0.0007	0.0091/ 0.0007
<u>Extractable</u>			
Ca %	0.051 / 0.0056	0.028 / 0.0023	0.0637/ 0.0079
Mg %	0.007 / 0.0001	0.0037/ 0.007	0.0083/ 0.0003
K %	0.0075/ 0.0004	0.002 / 0.0001	0.0094/ 0.0005
C.E.C. meq/100g	5.06 / 0.117	2.49 / 0.179	5.53 / 0.71
Organic Matter %	2.73 / 0.45	2.05 / 0.42	5.03 / 0.97
<u>Texture</u>			
Sand %	68.2 / 1.1		
Silt %	19.8 / 0.8		
Clay %	12.0 / 1.3		

Table 6. Nutrient and heavy metal content of the total, sand, and fine fractions of the bank material at Heber WS. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.22 / 0.070	0.077 / 0.017	0.440 / 0.106
Mg %	0.128 / 0.052	0.034 / 0.009	0.261 / 0.066
Na ppm	23 / 4.16	11.3 / 2.96	87.3 / 8.9
K %	0.096 / 0.026	0.028 / 0.003	0.195 / 0.029
Zn ppm	23.0 / 6.3	9.4 / 4.5	48.3 / 8.65
Fe %	0.899 / 0.339	0.273 / 0.102	1.74 / 0.42
Cu ppm	15.5 / 5.9	5.67 / 2.2	41.6 / 18.2
Mn %	0.027 / 0.002	0.0113/ 0.0019	0.051 / 0.0015
Pb ppm	9.0 / 1.0	4.0 / 0.58	15.0 / 1.5
Cd ppm	0.50 / —	0.39 / —	0.20 / —
<u>Total</u>			
N %	0.070 / 0.005	0.036 / 0.004	0.109 / 0.011
P %	0.021 / 0.003	0.007 / 0.0004	0.026 / 0.002
<u>Extractable</u>			
Ca %	0.217 / 0.070	0.137 / 0.045	0.311 / 0.085
Mg %	0.048 / 0.026	0.027 / 0.014	0.063 / 0.027
K %	0.017 / 0.0044	0.0067/0.0020	0.022 / 0.004
C.E.C. meq/100g	18.4 / 7.1	8.95 / 2.9	23.2 / 5.6
Organic Matter %	6.0 / 1.1	3.67 / 0.37	10.9 / 1.8
<u>Texture</u>			
Sand %	64.6 / 5.2		
Silt %	16.3 / 2.2		
Clay %	19.2 / 7.2		

Table 7. Nutrient and heavy metal content of the total, sand, and fine fractions of the rock step material at Heber WS. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl Digestable</u>			
Ca %	0.233 / 0.009	0.166 / 0.025	0.495 / 0.015
Mg %	0.103 / 0.019	0.065 / 0.009	0.283 / 0.027
Na ppm	24.7 / 0.88	20.7 / 9.7	79.7 / 6.2
K %	0.078 / 0.008	0.050 / 0.007	0.202 / 0.0185
Zn ppm	28.0 / 1.8	17.3 / 0.88	61.0 / 3.5
Fe %	1.06 / 0.22	0.824 / 0.235	1.67 / 0.08
Cu ppm	13.1 / 2.9	7.67 / 1.33	45.0 / 4.73
Mn %	0.030 / 0.003	0.035 / 0.009	0.055 / 0.008
Pb ppm	14.3 / 2.4	11.7 / 3.48	23.0 / 4.73
Cd ppm	0.79 / —	0.24 / —	0.46 / —
<u>Total</u>			
N %	0.095 / 0.004	0.072 / 0.007	0.155 / 0.036
P %	0.022 / 0.002	0.0123 / 0.0036	0.024 / 0.003
<u>Extractable</u>			
Ca %	0.222 / 0.025	0.145 / 0.030	0.317 / 0.004
Mg %	0.042 / 0.010	0.022 / 0.007	0.061 / 0.010
K %	0.015 / 0.0017	0.0053 / 0.0012	0.022 / 0.0007
C.E.C. meq/100g	16.7 / 2.3	8.57 / 1.95	28.8 / 1.6
Organic Matter %	9.39 / 2.47	5.89 / 0.74	14.2 / 2.49
<u>Texture</u>			
Sand %	74.8 / 4.85		
Silt %	9.97 / 1.67		
Clay %	15.2 / 3.43		

Table 8. Nutrient and heavy metal content of the total, sand, and fine fractions of the log step material at Heber WS. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.367 / 0.047	0.278 / 0.076	0.589 / 0.087
Mg %	0.132 / 0.013	0.084 / 0.016	0.277 / 0.019
Na ppm	41.3 / 6.06	16.0 / 2.9	83.3 / 2.6
K %	0.107 / 0.005	0.069 / 0.011	8.223 / 0.005
Zn ppm	35.9 / 0.42	30.7 / 8.7	71.3 / 6.0
Fe %	0.813 / 0.081	0.592 / 0.057	1.57 / 0.115
Cu ppm	20.1 / 1.02	19.7 / 8.6	50.0 / 7.09
Mn %	0.049 / 0.009	0.047 / 0.020	0.079 / 0.020
Pb ppm	19.0 / 3.2	20.3 / 10.5	37.3 / 12.2
Cd ppm	0.55 / —	0.28 / —	0.44 / —
<u>Total</u>			
N %	0.225 / 0.053	0.314 / 0.157	0.202 / 0.061
P %	0.028 / 0.003	0.0233 / 0.0094	0.021 / 0.006
<u>Extractable</u>			
Ca %	0.399 / 0.089	0.366 / 0.069	0.390 / 0.051
Mg %	0.054 / 0.008	0.047 / 0.0045	0.056 / 0.0047
K %	0.024 / 0.004	0.013 / 0.0023	0.032 / 0.005
C.E.C. meq/100g	34.1 / 8.5	21.5 / 3.3	30.7 / 12.1
Organic Matter %	16.4 / 3.98	15.9 / 5.2	19.3 / 6.3
<u>Texture</u>			
Sand %	72.8 / 5.14		
Silt %	9.7 / 4.1		
Clay %	17.5 / 1.2		

Table 9. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under ponderosa pine at Sacramento Mtns. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	3.14 / 0.662	3.71 / 0.940	2.74 / 0.577
Mg %	0.714 / 0.138	0.379 / 0.130	0.812 / 0.139
Na ppm	126 / 3.79	40.3 / 7.42	124 / 6.03
K %	0.483 / 0.030	0.208 / 0.015	0.499 / 0.027
Zn ppm	46.3 / 6.0	30.53 / 5.94	59.7 / 9.17
Fe %	1.66 / 0.140	0.828 / 0.067	1.77 / 0.16
Cu ppm	17.0 / 1.2	8.67 / 1.20	24.0 / 2.1
Mn %	0.044 / 0.02	0.028 / 0.004	0.047 / 0.007
Pb ppm	7.7 / 2.2	10.3 / 1.2	8.33 / 1.33
Cd ppm	0.38 / —	0.36 / —	0.47 / —
<u>Total</u>			
N %	0.275 / 0.007	0.127 / 0.044	0.311 / 0.003
P %	0.062 / 0.002	0.028 / 0.008	0.066 / 0.004
<u>Extractable</u>			
Ca %	1.09 / 0.107	0.715 / 0.148	1.01 / 0.146
Mg %	0.053 / 0.046	0.031 / 0.012	0.056 / 0.018
K %	0.042 / 0.004	0.012 / 0.002	0.052 / 0.007
C.E.C. meq/100g	32.0 / 3.03	19.2 / 2.50	46.5 / 6.28
Organic Matter %	10.9 / 0.16	10.1 / 1.61	11.8 / 1.43
<u>Texture</u>			
Sand %	39.9 / 4.2		
Silt %	26.4 / 3.2		
Clay %	33.7 / 2.4		

Table 10. Nutrient and heavy metal content of the total, sand, and fine fractions of the bank material at Sacramento Mtns. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	3.54 / 0.37	3.06 / 1.59	3.62 / 0.15
Mg %	0.794 / 0.147	0.329 / 0.140	0.928 / 0.176
Na ppm	115 / 1.0	29.7 / 5.7	118 / 10.1
K %	0.451 / 0.042	0.129 / 0.032	0.468 / 0.039
Zn ppm	57.0 / 5.5	25.2 / 6.9	71.7 / 4.33
Fe %	1.868 / 0.080	0.602 / 0.149	2.09 / 0.129
Cu ppm	17.3 / 0.67	7.0 / 1.0	22.0 / 1.7
Mn %	0.046 / 0.002	0.019 / 0.002	0.051 / 0.002
Pb ppm	24.3 / 15.8	8.67 / 6.23	15.7 / 7.7
Cd ppm	1.00 / —	0.27 / —	0.66 / —
<u>Total</u>			
N %	0.138 / 0.046	0.061 / 0.032	0.160 / 0.058
P %	0.083 / 0.001	0.023 / 0.005	0.062 / 0.002
<u>Extractable</u>			
Ca %	1.19 / 0.069	0.565 / 0.229	0.790 / 0.235
Mg %	0.036 / 0.005	0.016 / 0.009	0.042 / 0.006
K %	0.019 / 0.004	0.004 / 0.003	0.028 / 0.006
C.E.C. meq/100g	29.2 / 3.45	10.8 / 2.8	38.4 / 7.2
Organic Matter %	7.16 / 2.0	3.63 / 1.9	9.12 / 2.3
<u>Texture</u>			
Sand %	29.9 / 3.9		
Silt %	30.5 / 2.8		
Clay %	39.6 / 1.2		

Table 11. Nutrient and heavy metal content of the total, sand, and fine fractions of the sediment material at Sacramento Mtns. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl Digestable</u>			
Ca %	2.76 / 0.61	4.16 / 1.3	2.83 / 0.74
Mg %	0.955 / 0.19	0.203 / 0.051	1.10 / 0.24
Na ppm	112 / 6.0	33.3 / 13.8	99.7 / 5.25
K %	0.463 / 0.017	0.025 / 0.002	0.422 / 0.013
Zn ppm	53.7 / 4.9	7.30 / 0.75	72.7 / 5.2
Fe %	1.83 / 0.07	0.163 / 0.022	2.14 / 0.038
Cu ppm	26.3 / 11.3	2.3 / 0.88	27.0 / 7.6
Mn %	0.044 / 0.003	0.007 / 0.001	0.051 / 0.004
Pb ppm	10.7 / 2.7	3.0 / 0.58	13.3 / 2.6
Cd ppm	0.78 / —	0.33 / —	0.85 / —
<u>Total</u>			
N %	0.157 / 0.023	0.031 / 0.004	0.189 / 0.026
P %	0.048 / 0.006	0.010 / 0.0003	0.058 / 0.008
<u>Extractable</u>			
Ca %	1.14 / 0.129	0.688 / 0.178	1.15 / 0.112
Mg %	0.035 / 0.006	0.018 / 0.008	0.041 / 0.007
K %	0.027 / 0.002	0.008 / 0.002	0.036 / 0.004
C.E.C. meq/100g	38.9 / 10.5	18.5 / 4.9	20.3 / 5.5
Organic Matter %	8.02 / 1.3	4.14 / 0.60	10.2 / 1.4
<u>Texture</u>			
Sand %	39.6 / 4.9		
Silt %	22.1 / 7.0		
Clay %	38.3 / 2.3		

Table 12. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under ponderosa pine at Tesuque WS. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCl</u>			
<u>Digestable</u>			
Ca %	0.947 / 0.21	0.483 / 0.44	0.823 / 0.12
Mg %	0.455 / 0.02	0.313 / .03	0.685 / 0.08
Na ppm	84.3 / 2.3	47.0 / 3.0	81.7 / 7.4
K %	0.186 / 0.039	0.104 / 0.19	0.259 / 0.04
Zn ppm	39.7 / 3.2	32.0 / 8.7	54.3 / 2.2
Fe %	2.60 / 0.13	2.33 / 0.43	2.80 / 0.25
Cu ppm	9.0 / 2.0	5.33 / 0.88	17.7 / 0.88
Mn %	0.0517/ 0.003	0.0384/ 0.006	0.063 / 0.004
Pb ppm	5.3 / 1.20	6.0 / 2.1	11.0 / 2.1
Cd ppm	0.10 / —	0.28 / —	0.16 / —
<u>Total</u>			
N %	0.087 / 0.017	0.054 / 0.018	0.155 / 0.038
P %	0.057 / 0.008	0.044 / 0.004	0.073 / 0.014
<u>Extractable</u>			
Ca %	0.226 / 0.025	0.159 / 0.038	0.281 / 0.026
Mg %	0.044 / 0.009	0.028 / 0.011	0.054 / 0.009
K %	0.017 / 0.002	0.006 / 0.001	0.024 / 0.003
C.E.C. meq/100g	16.5 / 2.6	— / —	8.18 / 2.8
Organic Matter %	6.28 / 0.71	4.30 / 0.46	8.17 / 1.76
<u>Texture</u>			
Sand %	61.6 / 3.4		
Silt %	24.3 / 1.6		
Clay %	14.1 / 2.2		

Table 13. Nutrient and heavy meatal content of the total, sand, and fine fractions of the bank material at the Tesuque Watershed. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCL</u>			
<u>Digestable</u>			
Ca %	0.908 / 0.067	0.687 / 0.076	0.848 / 0.149
Mg %	0.568 / 0.053	0.611 / 0.092	0.572 / 0.024
Na ppm	98.0 / 12.2	44.0 / 4.4	91.3 / 12.4
K %	0.210 / 0.060	0.151 / 0.050	0.244 / 0.049
Zn ppm	48.0 / 10.6	42.9 / 9.5	64.3 / 10.1
Fe %	2.37 / 0.14	2.50 / 0.22	2.55 / 0.13
Cu ppm	27.3 / 0.14	12.3 / 4.4	64.3 / 2.6
Mn %	0.053 / 0.012	0.050 / 0.011	0.053 / 0.009
Pb ppm	10.3 / 3.8	15.0 / 6.5	15.3 / 4.3
Cd ppm	0.09 / ---	0.29 / ---	0.12 / ---
<u>Total</u>			
N %	0.202 / 0.07	0.191 / 0.07	0.193 / 0.04
P %	0.072 / 0.005	0.073 / 0.009	0. 072 / 0.005
<u>Extractable</u>			
Ca %	0.364 / 0.05	0.325 / 0.08	0.355 / 0.02
Mg %	0.045 / 0.002	0.034 / 0.004	0.048 / 0.003
K %	0.015 / 0.005	0.008 / 0.003	0.022 / 0.003
C.E.C. meq/100g	25.7 / 4.9	5.5 / ---	25.9 / ---
Organic Matter %	12.3 / 4.3	17.3 / 6.4	11.5 / 2.5
<u>Texture</u>			
Sand %	69.8 / 2.0		
Silt %	17.1 / 1.7		
Clay %	13.0 / 0.59		

Table 14. Nutrient and heavy metal content of the total, sand, and fine fractions of sediment material at Tesuque Watershed. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
<u>HNO₃-HCL</u>			
<u>Digestable</u>			
Ca %	0.968 / 0.100	0.681 / 0.109	0.992 / 0.030
Mg %	0.646 / 0.076	0.582 / 0.047	0.702 / 0.09
Na ppm	100.3 / 6.06	62.0 / 5.7	117 / 21.6
K %	0.176 / 0.032	0.128 / 0.026	0.226 / 0.014
Zn ppm	61.0 / 10.1	46.4 / 1.8	67.0 / 3.2
Fe %	3.186 / 0.425	3.04 / 0.384	3.34 / 0.35
Cu ppm	15.0 / 5.0	13.3 / 1.76	53.3 / 16.4
Mn %	0.057 / 0.004	0.052 / 0.003	0.064 / 0.004
Pb ppm	11.7 / 1.5	15.3 / 3.8	17.7 / 2.2
Cd ppm	0.11 / ---	0.44 / ---	0.09 / ---
<u>Total</u>			
N %	0.154 / 0.07	0.144 / 0.07	0.184 / 0.05
P %	0.089 / 0.012	0.088 / 0.01	0.102 / 0.014
<u>Extractable</u>			
Ca %	0.357 / 0.13	0.3343 / 0.110	0.306 / 0.004
Mg %	0.055 / 0.014	0.046 / 0.013	0.059 / 0.007
K %	0.011 / 0.011	0.006 / 0.002	0.014 / 0.003
C.E.C. meq/100g	23.0 / 8.2	--- / ---	--- / ---
Organic Matter %	8.61 / 4.2	10.8 / 4.7	9.37 / 1.5
<u>Texture</u>			
Sand %	73.5 / 4.6		
Silt %	15.0 / 4.0		
Clay %	11.5 / 1.1		

Table 15. Nutrient and heavy metal content of the total, sand, and fine fractions of the 0-15 cm depth soil under mixed conifer at Thomas Creek. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
$\text{HNO}_3\text{-HCl}$			
<u>Digestable</u>			
Ca %	0.900 / 0.13	0.850 / 0.14	0.808 / 0.11
Mg %	0.860 / 0.03	1.45 / 0.11	0.624 / 0.02
Na ppm	13.1 / 0.40	126 / 14.6	90.3 / 10.2
K %	0.443 / 0.041	0.272 / 0.03	0.433 / 0.05
Zn ppm	144 / 9.1	107 / 8.5	139 / 7.7
Fe %	4.93 / 0.09	5.84 / 0.21	4.03 / 0.14
Ca ppm	60.7 / 6.7	55.7 / 2.2	50.3 / 0.67
Mn %	0.158 / 0.004	0.171 / 0.01	0.135 / 0.003
Pb ppm	17.3 / 4.4	10.7 / 1.5	14.0 / 1.5
Cd ppm	0.33 / —	0.31 / —	0.27 / —
<u>Total</u>			
N %	0.313 / 0.03	0.166 / 0.03	0.227 / 0.003
P %	0.277 / 0.02	0.253 / 0.02	0.183 / 0.003
<u>Extractable</u>			
Ca %	0.635 / 0.08	0.636 / 0.11	0.630 / 0.08
Mg %	0.047 / 0.001	0.045 / 0.002	0.045 / 0.001
K %	0.125 / 0.03	0.147 / 0.02	0.182 / 0.04
C.E.C. meq/100g	54.1 / 4.7	50.8 / 4.0	50.8 / 3.5
Organic Matter %	14.2 / 0.05	15.8 / 0.53	14.6 / 0.10
<u>Texture</u>			
Sand %	39.3 / 1.8		
Silt %	38.3 / 1.8		
Clay %	22.4 / 0.18		

Table 16. Nutrient and heavy metal content of the total, sand, and fine fractions of the bank material at Thomas Creek. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
$\text{HNO}_3\text{-HCl}$			
<u>Digestable</u>			
Ca %	0.68 / 0.07	0.529 / 0.07	0.727 / 0.07
Mg %	0.615 / 0.04	1.61 / 0.10	0.642 / 0.003
Na ppm	109 / 11.0	113 / 21.0	133 / 15.0
K %	0.216 / 0.03	0.163 / 0.06	0.272 / 0.04
Zn ppm	79.9 / 13.6	87.5 / 13.5	104.5 / 17.5
Fe %	3.64 / 0.15	6.20 / 0.41	4.13 / 0.09
Cu ppm	52.7 / 11.0	45.5 / 7.5	66.5 / 10.5
Mn %	0.139 / 0.004	0.166 / 0.02	0.135 / 0.004
Pb ppm	83.0 / 71.0	43.0 / 36.0	84.0 / 71.0
Cd ppm	0.17 / —	0.32 / —	0.23 / —
<u>Total</u>			
N %	0.370 / 0.02	— / —	0.245 / 0.02
P %	0.160 / 0.024	— / —	0.105 / 0.012
<u>Extractable</u>			
Ca %	0.521 / 0.020	0.483 / 0.06	0.539 / 0.020
Mg %	0.097 / 0.02	0.091 / 0.02	0.098 / 0.02
K %	0.033 / 0.003	0.055 / 0.02	— / —
C.E.C. meq/100g	51.4 / 0.27	46.8 / 1.00	49.8 / 3.5
Organic Matter %	14.2 / 0.95	— / —	16.5 / 0.87
<u>Texture</u>			
Sand %	26.7 / 2.6		
Silt %	41.6 / 2.4		
Clay %	31.6 / 4.9		

Table 17. Nutrient and heavy metal content of the total, sand, and fine fractions of the rock step material at Thomas Creek. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
$\text{HNO}_3\text{-HCl}$			
<u>Digestable</u>			
Ca %	0.737 / 0.01	0.600 / 0.02	0.745 / 0.02
Mg %	0.927 / 0.04	1.74 / 0.12	0.682 / 0.010
Na ppm	18.8 / 0.296	132 / 1.5	170.7 / 5.8
K %	0.230 / 0.006	0.116 / 0.004	0.226 / 0.002
Zn ppm	97.3 / 2.4	97.0 / 6.4	99.3 / 3.3
Fe %	5.74 / 0.22	7.43 / 0.17	5.65 / 1.2
Cu ppm	55.0 / 3.22	45.0 / 2.1	58.3 / 3.4
Mn %	0.157 / 0.005	0.168 / 0.02	0.177 / 0.04
Pb ppm	17.0 / 2.6	6.30 / 3.9	15.0 / 3.6
Cd ppm	0.28 / —	0.33 / —	0.34 / —
<u>Total</u>			
N %	0.267 / 0.03	0.057 / 0.002	0.170 / 0.03
P %	0.157 / 0.009	0.223 / 0.013	0.103 / 0.02
<u>Extractable</u>			
Ca %	0.524 / 0.024	0.326 / 0.03	0.529 / 0.02
Mg %	0.125 / 0.006	0.081 / 0.007	0.120 / 0.005
K %	0.035 / 0.006	0.035 / 0.002	0.050 / 0.001
C.E.C. meq/100g	57.4 / 7.0	36.6 / 2.9	43.5 / 1.5
Organic Matter %	— / —	8.57 / 8.7	16.33 / 0.42
<u>Texture</u>			
Sand %	— / —		
Silt %	— / —		
Clay %	— / —		

Table 18. Nutrient and heavy metal content of the total, sand, and fine fractions of log step material at Thomas Creek. Values expressed as mean/standard error.

<u>ANALYSIS</u>	<u>TOTAL</u>	<u>SAND</u>	<u>FINE</u>
$\text{HNO}_3\text{-HCl}$			
<u>Digestable</u>			
Ca %	0.983 / 0.04	0.959 / 0.14	1.091 / 0.06
Mg %	0.66 / 0.02	0.70 / 0.18	0.623 / 0.03
Na ppm	17.53 / 0.38	72.7 / 15.3	164 / 3.28
K %	0.223 / 0.007	0.083 / 0.013	0.223 / 0.0003
Zn ppm	129 / 17.6	83.0 / 7.1	121 / 6.2
Fe %	4.017 / 0.154	3.33 / 0.93	2.82 / 0.49
Cu ppm	106 / 16.6	65.0 / 6.03	98.3 / 11.3
Mn %	0.136 / 0.009	0.108 / 0.014	0.123 / 0.006
Pb ppm	42.0 / 11.0	18.0 / 7.8	44.0 / 8.5
Cd ppm	0.27 / —	0.49 / —	0.26 / —
<u>Total</u>			
N %	0.587 / 0.05	0.496 / 0.14	0.513 / 0.05
P %	0.153 / 0.003	0.122 / 0.010	0.110 / 0.000
<u>Extractable</u>			
Ca %	0.845 / 0.052	0.796 / 0.05	0.803 / 0.07
Mg %	0.169 / 0.008	0.162 / 0.009	0.157 / 0.005
K %	0.054 / 0.002	0.039 / 0.002	0.064 / 0.01
C.E.C. meq/100g	77.0 / 6.2	72.8 / 3.2	57.7 / 1.7
Organic Matter %	26.28 / 3.91	— / —	31.10 / 2.79
<u>Texture</u>			
Sand %	— / —		
Silt %	— / —		
Clay %	— / —		

Table 19. Comparisons of average acid-digestable element concentrations of soil, stream bank, and stream channel sediments from limestone (L), basalt (B), granite (G), and sandstone (S) geologies. Values within a row of a size category followed by different letters are significantly different ($p < .05$)

Element	Soil							
	Fines(<0.061 mm)				Sand(0.061-2.0 mm)			
	L	B	G	S	L	B	G	S
Ca%	2.74a	0.57b	0.90b	0.14b	3.72a	0.31b	0.37b	0.04b
Mg%	0.81a	0.68a	0.68a	0.14b	0.38b	6.48a	0.73b	0.02b
K %	0.45a	0.24b	0.26b	0.12c	0.21a	0.04c	0.10b	0.02c
Fe%	1.8 c	4.9 a	2.8 b	1.1 d	0.8 c	11.4 a	2.3 b	0.2 c
Mn%	0.05bc	0.10a	0.06b	0.03c	0.03b	0.15a	0.04b	0.01c
Na ppm	90.3 b	201.0 a	81.7 c	58.7 d	40.3 b	127.7 a	47.0 b	6.7 c
Zn ppm	59.7 a	66.3 a	54.3 a	30.7 b	30.5 b	126.3 a	32.0 b	6.0 c
Cu ppm	24.0 b	71.3 a	17.7 b	20.7 b	8.7 b	52.3 a	5.3 bc	2.0 c
Pb ppm	8.3 a	9.0 a	11.0 a	20.3 a	10.3 a	1.7 b	6.0 ab	3.7 b
Total N%	0.31a	0.19b	0.16b	0.05c	0.12a	0.09a	0.05a	0.04a
Total P%	0.07a	0.05a	0.07a	0.01b	0.03c	0.08a	0.04b	0.004d
Cd ppm	0.47	0.26	0.16	0.11	0.36	0.36	0.23	<0.01

Element	Stream Bank							
	Fines				Sands			
	L	B	G	S	L	B	G	S
Ca%	3.62a	0.87b	0.85b	0.44b	3.06a	0.38ab	0.69ab	0.08b
Mg%	0.93a	0.54b	0.57b	0.26b	0.33bc	3.97a	0.61b	0.03c
K %	0.468a	0.320b	0.244b	0.195b	0.13ab	0.09ab	0.15a	0.03b
Fe%	2.09bc	3.61a	2.55b	1.74c	0.60c	10.10a	2.50b	0.30c
Mn%	0.051b	0.126a	0.053b	0.051b	0.019c	0.299a	0.050b	0.011c
Na ppm	118.0b	227.7a	91.3b	87.3b	29.7b	249.0a	44.0b	11.3c
Zn ppm	71.7b	97.0a	64.3b	48.3b	25.2bc	116.7a	42.9b	9.3c
Cu ppm	22.0a	45.7a	65.7a	41.7a	7.0b	44.7a	12.3b	5.7b
Pb ppm	15.7a	10.3a	15.3a	15.0a	2.50a	8.7a	15.0a	4.0a
Total N%	0.160b	0.408a	0.193b	0.109b	0.061ab	0.064ab	0.191a	0.036b
Total P%	0.0618b	0.098a	0.0723b	0.0257c	0.0227c	0.126a	0.0727b	0.0070c
Cd ppm	0.66	0.36	0.12	0.20	0.27	0.48	0.29	0.39

Element	Stream Channel							
	Fines				Sands			
	L	B	G	S	L	B	G	S
Ca%	2.83a	0.572b	0.989b	0.495b	4.16a	0.417b	0.631b	0.166b
Mg%	1.101a	0.818a	0.702ab	0.283b	0.203b	3.62a	0.532b	0.065b
K %	0.472	0.189b	0.226b	0.202b	0.025b	0.052b	0.128a	0.050b
Fe%	2.140c	5.105a	3.340b	1.667c	0.163c	8.76a	3.04b	0.824c
Mn%	0.051b	0.189a	0.064b	0.055b	0.007b	0.357a	0.052b	0.035b
Na ppm	100. b	448. a	117. b	80. b	33. bc	580. a	62. b	21. c
Zn ppm	72.7a	70.7a	67.0a	61.0a	7.3d	88. a	46.4b	17.3c
Cu ppm	27.0b	91.7a	53.3b	45.0b	2.3d	53.0a	13.3b	7.7c
Pb ppm	13.3a	14.7a	17.7a	23.0a	3.0c	7.3bc	15.3a	11.7ab
Total N%	0.189a	0.070b	0.184ab	0.155ab	0.031a	0.026a	0.145a	0.072a
Total P%	0.058b	0.065b	0.102a	0.024c	0.010b	0.098a	0.088a	0.012b
Cd ppm	0.85	0.32	0.09	0.46	0.33	0.59	0.44	0.24

Table 20. Comparisons of average extractable element concentrations, cation exchange capacity (C.E.C.), and organic matter of soil, stream bank, and stream channel sediments from limestone (L), basalt (B), granite (G), and sandstone (S) geologies. Values within a row of a size category followed by different letters are significantly different ($p < .05$)

<u>Soil</u>								
<u>Element</u>	<u>Fines(<0.061 mm)</u>				<u>Sands(0.061-2.0 mm)</u>			
	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>
Ca%	1.01a	0.49b	0.28bc	0.06c	0.72a	0.36b	0.16bc	0.03c
Mg%	0.06b	0.10a	0.05b	0.01c	0.03b	0.08a	0.03b	0.004b
K %	0.052a	0.035b	0.024b	0.009c	0.012b	0.020a	0.006c	0.002c
C.E.C. (^{meq} /100g)	46.5 a	35.3 a	47.8 a	5.5 b	19.2 a	27.4 a	8.2 b	2.5 b
Organic Matter %	11.8 ab	12.6 a	8.2 bc	5.0 c	10.0 a	9.1 a	4.3 b	2.0 b

<u>Stream Bank</u>								
	<u>Fines</u>				<u>Sands</u>			
	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>
Ca%	0.79a	0.71ab	0.35ab	0.31b	0.565a	0.438a	0.325a	0.137a
Mg%	0.042a	0.091a	0.048a	0.063a	0.016b	0.064a	0.034ab	0.027b
K %	0.028b	0.090a	0.023b	0.022b	0.0072b	0.052a	0.0083b	0.0067b
C.E.C. (^{meq} /100g)	38.4 a	42.5 a		23.2 a	10.8 b	38.7 a		8.9 b
Organic Matter %	9.11a	14.98a	11.52a	10.92a	3.63b	6.18b	17.32a	3.67b

<u>Stream Channel</u>								
	<u>Fines</u>				<u>Sands</u>			
	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>	<u>L</u>	<u>B</u>	<u>G</u>	<u>S</u>
Ca%	1.149a	0.243b	0.306b	0.317b	0.688a	0.138b	0.334b	0.145b
Mg%	0.041b	0.098a	0.059b	0.061b	0.018a	0.044a	0.046a	0.022a
K %	0.036a	0.023b	0.014b	0.022b	0.0081ab	0.0112a	0.0061ab	0.0053b
C.E.C. (^{meq} /100g)	20.3 b	44.8 a	35.9 ab	28.8 ab	18.5 a	13.5 a	13.1 a	8.6 a
Organic Matter %	10.2 a	8.7 a	9.4 a	14.2 a	4.1 a	4.5 a	10.8 a	5.9 a

Table 21. Nutrient, heavy metal, and organic characteristics of the fines fraction (<0.061mm) for the 0-15 cm soil depth under ponderosa and mixed conifer on basalt. Means followed by the same letter are not significantly different ($P>.05$).

<u>Analysis</u>	<u>Mixed Conifer</u>	<u>Ponderosa Pine</u>
<u>Acid-digestable</u>		
Ca %	0.808a	0.569a
Mg %	0.624a	0.675a
K %	0.433a	0.237a
Na ppm	90.3a	201.0b
Zn ppm	139.0a	66.3b
Fe %	4.03a	4.90b
Mn %	0.153a	0.104b
Cu ppm	50.3a	71.3b
Pb ppm	14.0a	9.0b
Total N %	0.227a	0.192a
Total P %	0.183a	0.049b
<u>Extractable</u>		
Ca %	0.630a	0.489a
Mg %	0.157a	0.098b
K %	0.182a	0.035b
C.E.C. meg/100g	50.8a	35.3b
Organic Matter %	14.6a	12.6b

Table 22. Cation and heavy metal content of the fines from Beaver Creek
WS-13 and transported sediment from Beaver Creek WS-19.

Component (sample %)	WS-13	WS-19
	<u>mean</u> std. error	
Ca	<u>0.569</u> 0.021	0.568
Mg	<u>0.675</u> 0.023	0.608
Na	<u>0.0201</u> 0.0008	0.0389
K	<u>0.237</u> 0.006	0.207
Fe	<u>4.90</u> 0.13	4.66
Zn	<u>0.0066</u> 0.0001	1.01
Cu	<u>0.0071</u> 0.0003	0.0105
Mn	<u>0.104</u> 0.006	0.072
Pb	<u>0.0009</u> 0.0001	0.0012

Table 23. Cation exchange capacity of suspended clays. (Expressed as mean/standard error)

		(C.E.C. meq/100g)
Beaver Creek	Ponderosa Pine 0-15 cm	85.35 / 4.05
	Oak 0-15 cm	98.0 / 2.54
	Bank	100.2 / 4.12
	Sediment	79.4 / 6.30
Thomas Creek	Mixed Conifer 0-15 cm	107.5 / 5.01
	Bank	98.9 / *
	Rock Step	95.4 / *
	Log Step	99.6 / 1.0
Tesuque Watershed	Ponderosa Pine 0-15 cm	131.1 / 23.5
	Bank	114.8 / 5.07
	Sediment	130.1 / 40.6
Heber Watershed	Ponderosa Pine 0-15 cm	58.8 / 16.08
	Bank	108.6 / 12.94
	Rock Step	100.8 / 9.93
	Log Step	71.1 / 14.9
Sacramento Mtns.	Ponderosa Pine 0-15 cm	99.9 / 4.13
	Bank	73.3 / 8.77
	Sediment	89.6 / 9.78

*indicates one or more replicate missing.

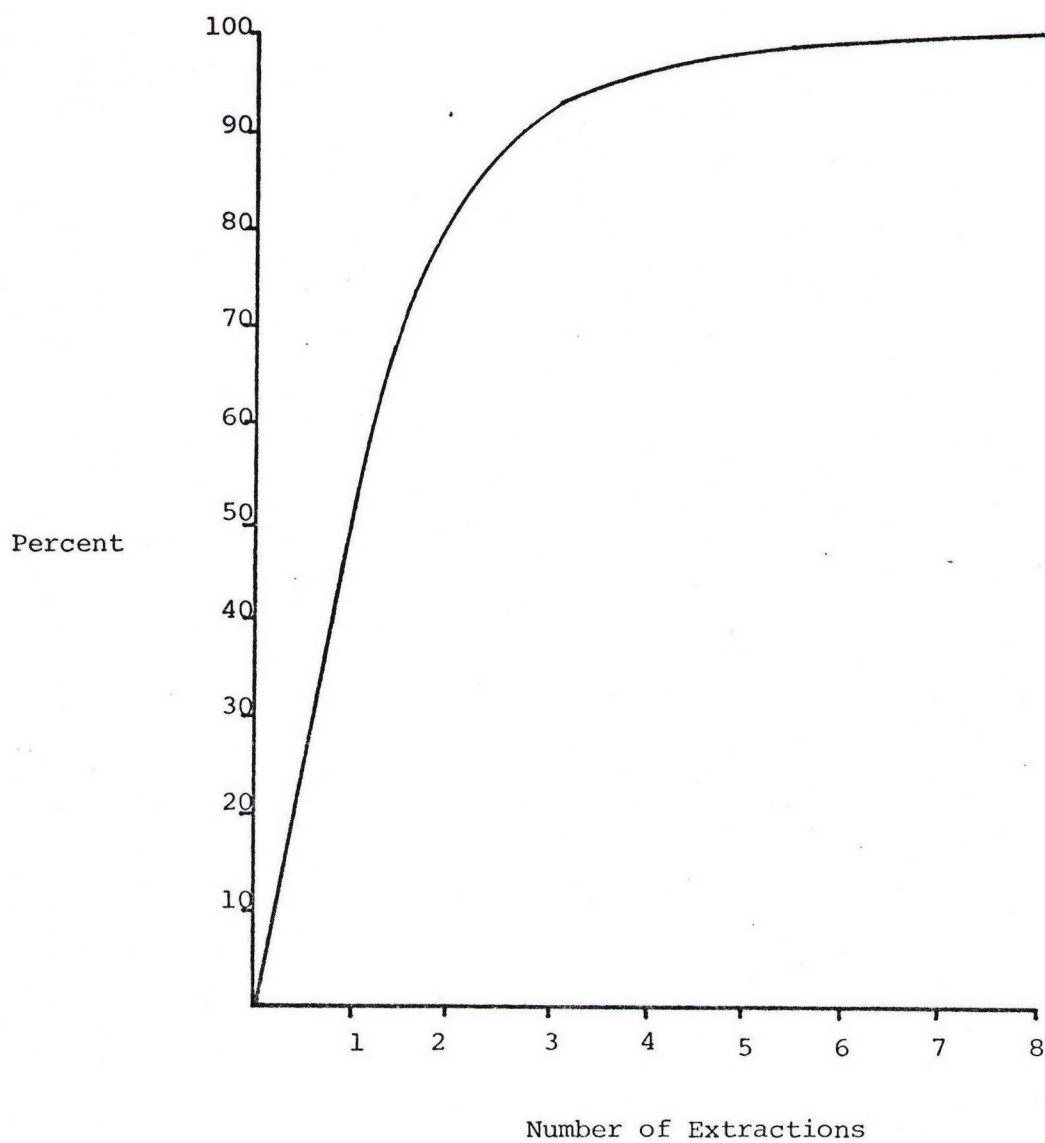


Fig. 1. Plot of the amount of extractable cations (expressed as a percent of the total) removed by eight extractions with 1.0 N ammonium acetate.

Beaver Creek

Ponderosa Pine	$\text{HNO}_3\text{-HCl}$	Extractable
0-15 cm	A	a
Oak, 0-15	B	b
Bank	C	c
Sediment	D	d

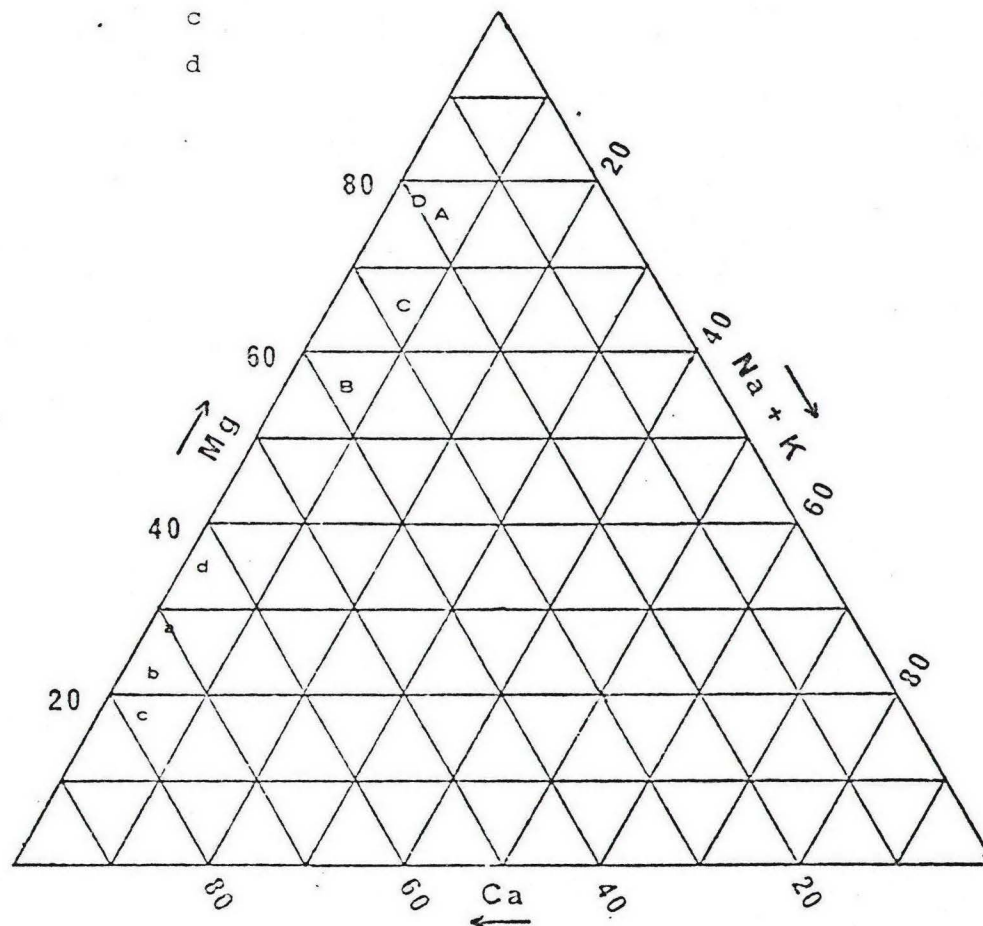


Fig. 2. Trilinear plot of the relative proportion of the major cations (extractable and digestable) for the samples collected at Beaver Creek WS-13.

Heber Sandstone

	<u>HNO₃-HCl</u>	<u>Extractable</u>
0-15 cm	A	a
Rock Step	B	b
Bank	C	c
Log Step	D	d

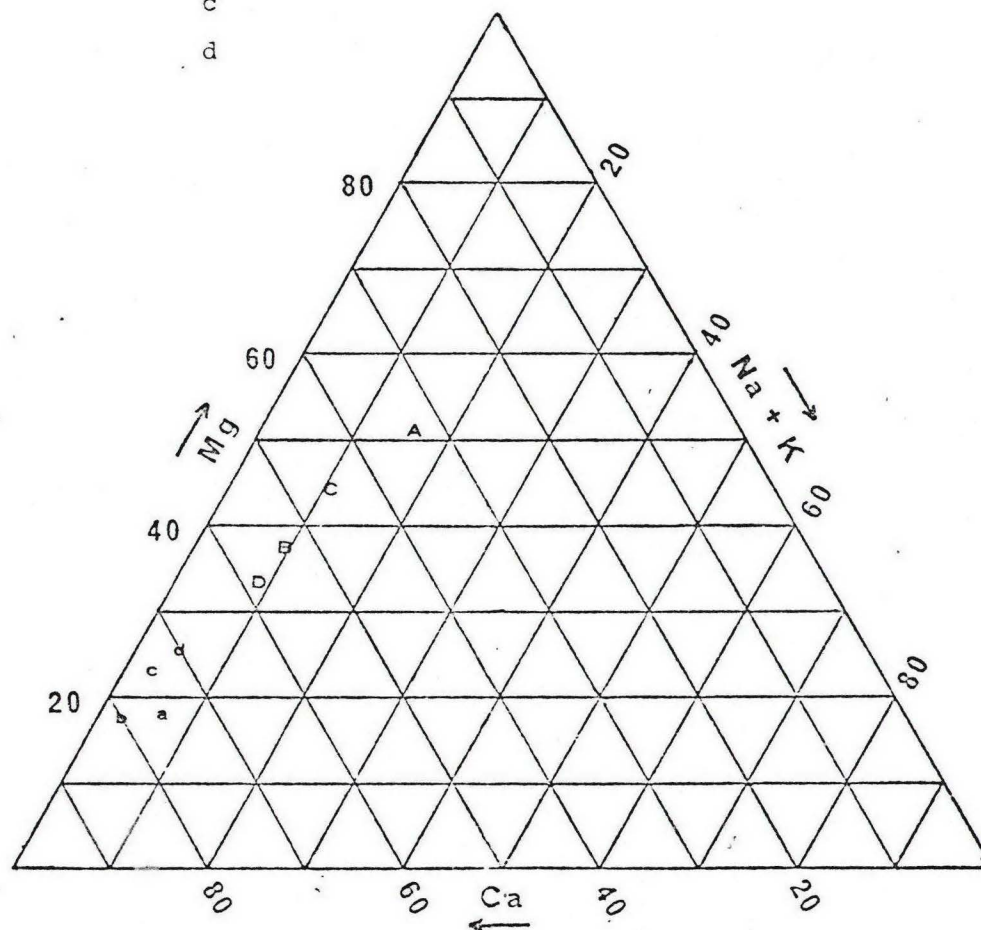


Fig. 3. Trilinear plot of the relative proportions of the major cations (extractable and digestable) for the samples collected from Heber Watershed.

Sacramento Mountains

	<u>HNO₃-HCl</u>	<u>Extractable</u>
0-15 cm	A	a
Bank	B	b
Sediment	C	c

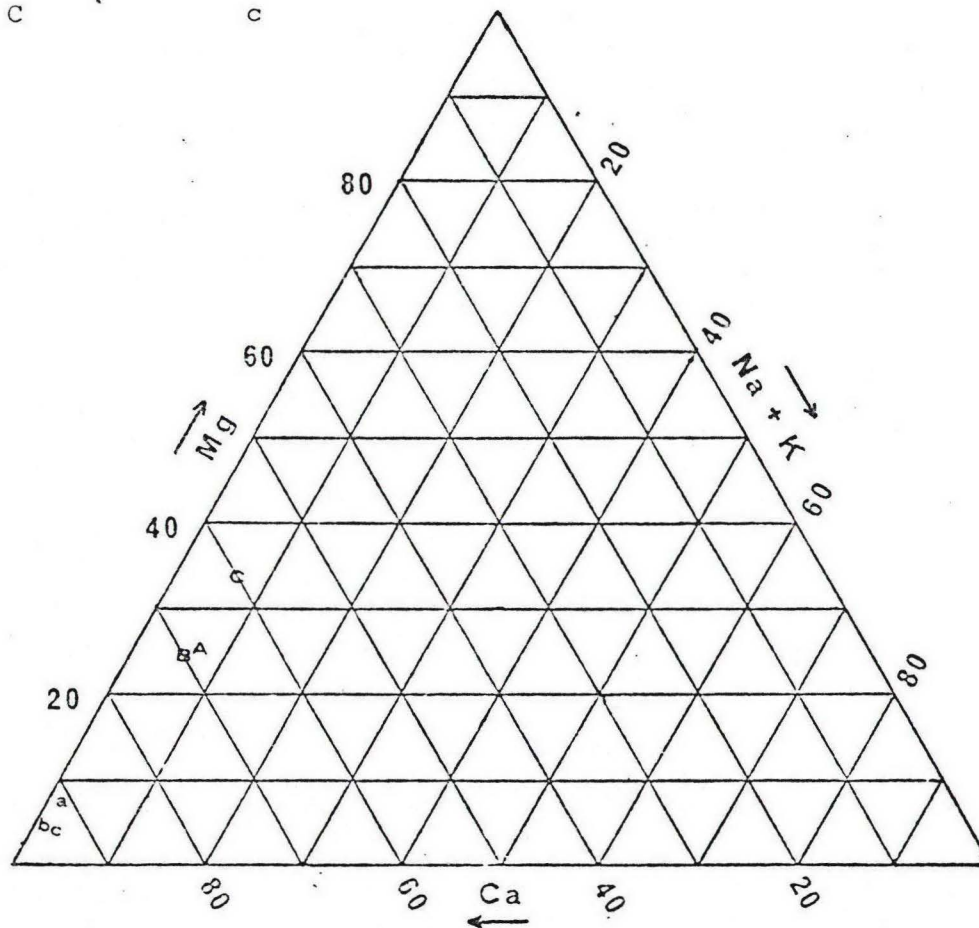


Fig. 4. Trilinear plot of the relative proportions of the major cations (extractable and digestable) for the samples collected from Sacramento Mountains.

Tesuque Watershed

	<u>HNO₃-HCl</u>	<u>Extractable</u>
0-15 cm	A	a
Bank	B	b
Sediment	C	c

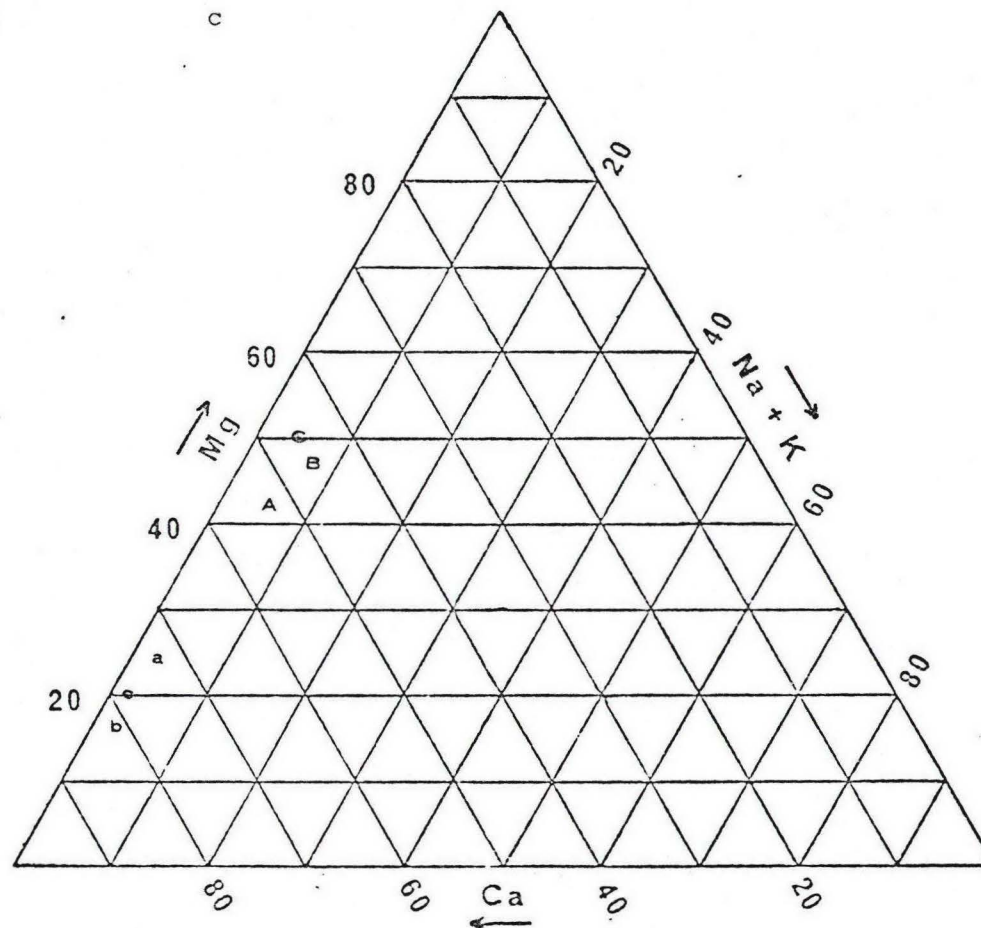


Fig. 5. Trilinear plot of the relative proportions of the major cations (extractable and digestable) for the samples collected at Tesuque Watershed.

	<u>HNO₃-HCl</u> 3	<u>Extractable</u>
Mixed Conifer		
0-15 cm	A	a
Bank	B	b
Rock Step	C	c
Log Step	D	d

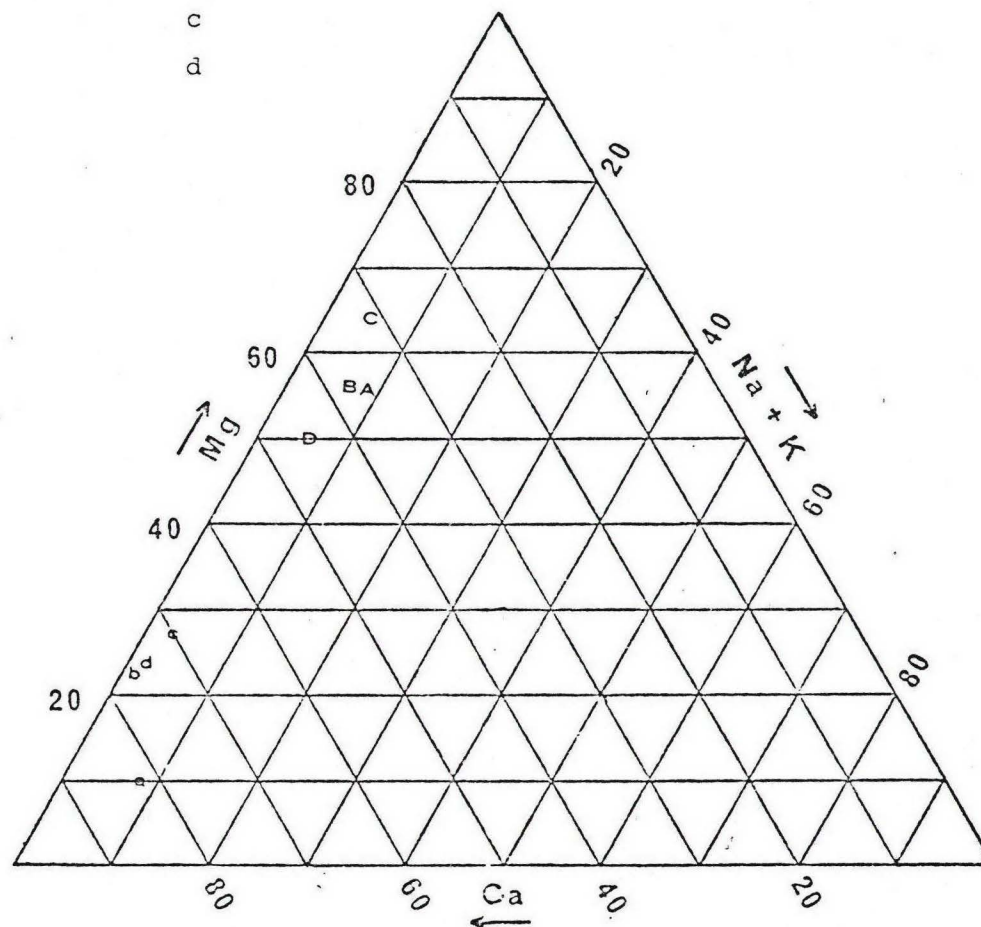
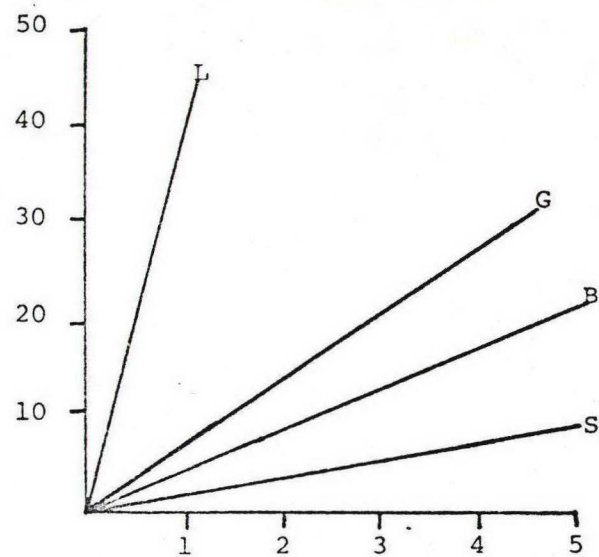
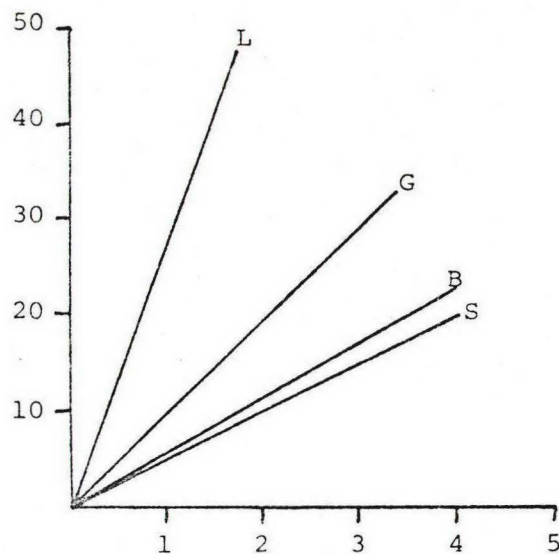


Fig. 6. Trilinear plot of the relative proportions of the major cations (extractable and digestable) for the samples collected at Thomas Creek.

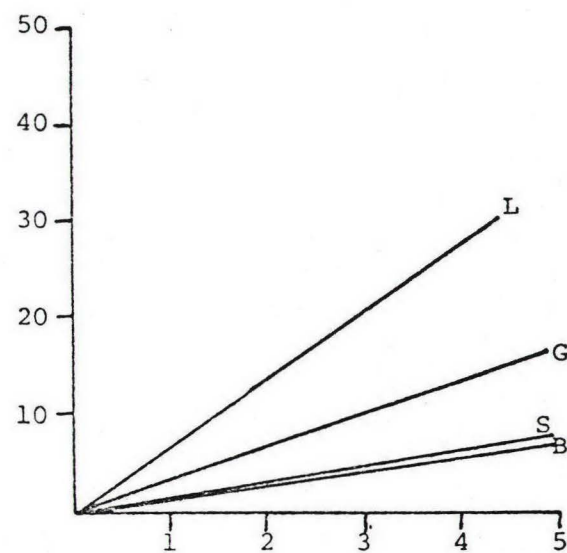
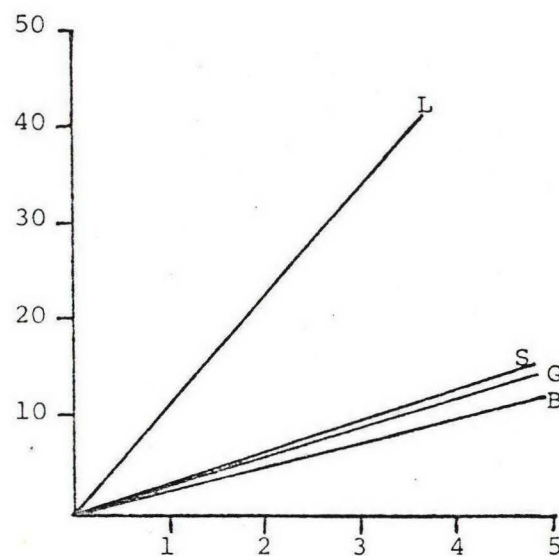
FINES

SANDS

Transport
of
Acid digestable
Ca
(g)



Transport
of
extractable
Ca
(g)



Transport of Sediment
(kg)

Figure 7. Influence of Sediment Transport (Fines and Sands) on the Transport of Acid-Digestable and Extractable Ca for Different geologies (L-limestone; G-granite; B-basalt; S-sandstone).